Quantum Optical Signals in Telecommunication Networks

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Introduction

Here we discuss the integration of quantum optical signals into modern telecommunication networks. The ability to establish quantum channels would allow the use of Quantum Information Technologies (QIT) in already deployed infrastructures. This benefits both of them: QIT can take advantage in terms of costs, resources and market share; and telecom networks can use QITs to solve some of their drawbacks (e.g., Quantum Key Distribution, QKD, can provide them with information-theoretically secure symmetric keys).

In particular, we focus on Metropolitan Area Networks (MAN) using Wavelength-Division Multiplexing (WDM). First, we propose a WDM grid that arranges quantum and classical signals together but in different spectrum bands. This choice aims to reduce the adverse noise effects over quantum signals. Then, we propose multiple network scenarios based on this WDM grid and standard commercial equipment. Scenarios resemble commercial telecom networks in order to use as much as existing infrastructure and components as possible, and ease its application in existing telecom networks.

1 Multiplexing Quantum Optical Signals

Modern telecom networks tend to use optical components, many of them also passive, and WDM [1]. Therefore, a direct optical path between two points can be established using a WDM channel. This optical path can be used as a quantum channel, thus enabling the transmission of quantum optical signals and, consequently, the integration of quantum information technologies. WDM allows the simultaneous transmission of optical signals within the same fiber by using different wavelengths. The use of WDM is standardized by ITU-T, which defines a grid of WDM channels uniformly distributed over an area of the spectrum. Each WDM channel is defined by its center wavelength (e.g., 1510.10 nm) and its separation from neighboring channels (20 nm for Coarse WDM, CWDM, and 1.6 nm-0.2 nm for Dense WDM, DWDM).

Ideally, QITs devices, such as QKD systems, would simply use one of these WDM channels to exchange optical qubits. But, the noise generated by the classical signals, 70-100 dB more powerful, would limit the quantum transmission by drastically increasing its signal-to-noise ratio (SNR) [2]. Instead of mixing all signals on the same band, in our WDM scheme, we arrange the signals depending on its power: quantum signals use wavelengths around the O band of the spectrum (1260-1360 nm), and the classical ones use the C band (1530-1565 nm). The resulting spectrum is depicted in Fig. 1. This allows to: (i) use standard telecom components for the classical signals, (ii) strongly reduce the noise due to the 200 nm separation, and (iii) ease their manipulation by keeping them in separated groups. Fiber absorptions in the O band increase ≈ 0.1 dB/km over C band, but this is a minor concern in MANs, since losses stem primarily from network components.

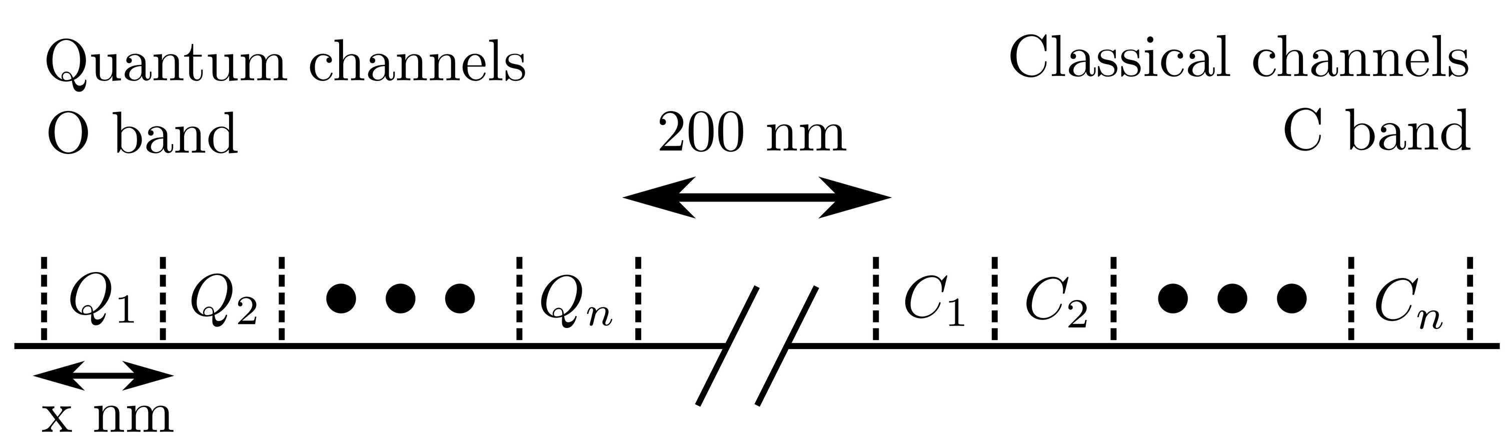

Fig. 1. Proposed WDM grid. It shows the arrangement of the quantum and classical signals within the optical spectrum. Quantum signals are placed at the O band and, 200 nm away, the classical signals are placed at the C band.

2 Quantum Access Network

Access networks are an essential part of MANs. Using a point-to-multipoint topology, they connect subscribers in the same area to a bigger structure through a node in a center office. In particular, access networks based on WDM, WDM-PONs, assign one or more WDM channels to each subscriber. The WDM channels are mux/demux via an Arrayed Waveguide Grating (AWG). The design of a Quantum WDM-PON access network using our WDM grid scheme is depicted in Fig. 2. Taking advantage of the periodicity of the AWG, multiple WDM channels can be assigned to each subscriber. Therefore, in our scenario, each one has a classical channel and its corresponding periodic quantum channel 200 nm away (this pair is represented in the figure using colored squares). Finally, band-pass filters are used at every node to separate quantum and classical signals. Except for these band-pass filters, the structure matches a real WDM-PON.

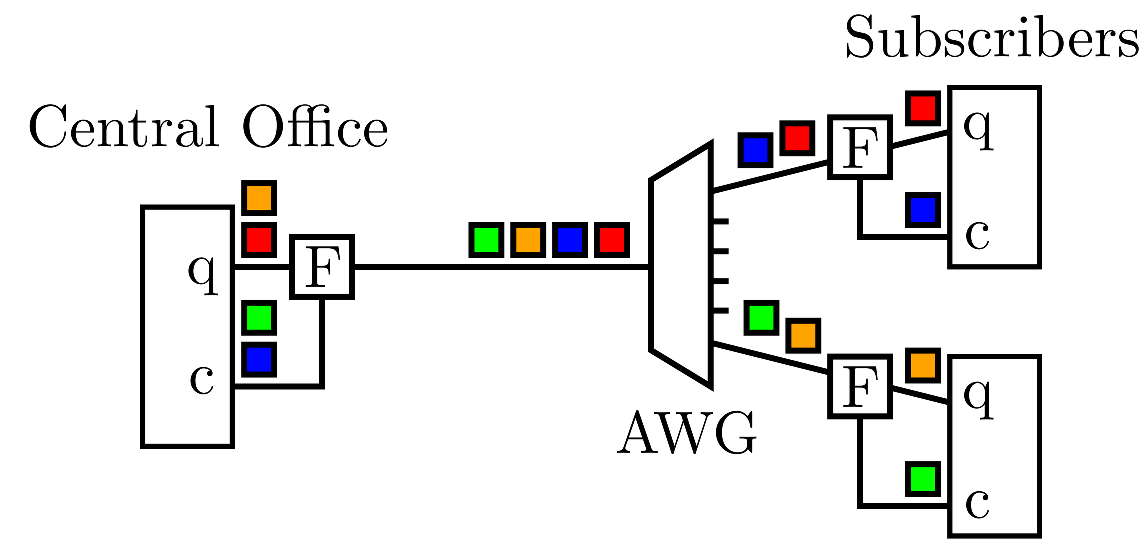

Fig. 2. Quantum WDM-PON Access Network. Our WDM grid scheme alongside the periodicity of the AWG allows to directly distribute a quantum and a classical signal to every subscriber. These signals are represented using colored squares. Band-pass filters are used near the entry of each node to separate both type of signals.

3 Quantum Metropolitan Area Network

Fig. 3 shows the design of a Quantum-MAN. The network is divided into WDM-PON access networks, like the ones previously described, and a DWDM backbone network, which interconnects all access networks. Each access network has assigned a quantum O-subband and the corresponding, AWG-periodic, C-subband for the associated classical channels. Here, subband refers to the group of quantum or classical channels of an access network. Dotted rectangles mark the network devices that we have modified according to our WDM scheme. In particular, backbone nodes route quantum and classical subbands to the corresponding access network using a series of band-pass filters and circulators. Besides, an optical switch is also added to the AWGs of the access networks in order to ensure all-to-all connectivity in the whole network. Therefore, a communication between two subscribers just require to select the destination by choosing the wavelength (WDM channel) and setting the correct port in the switch connected to the nearest AWG.

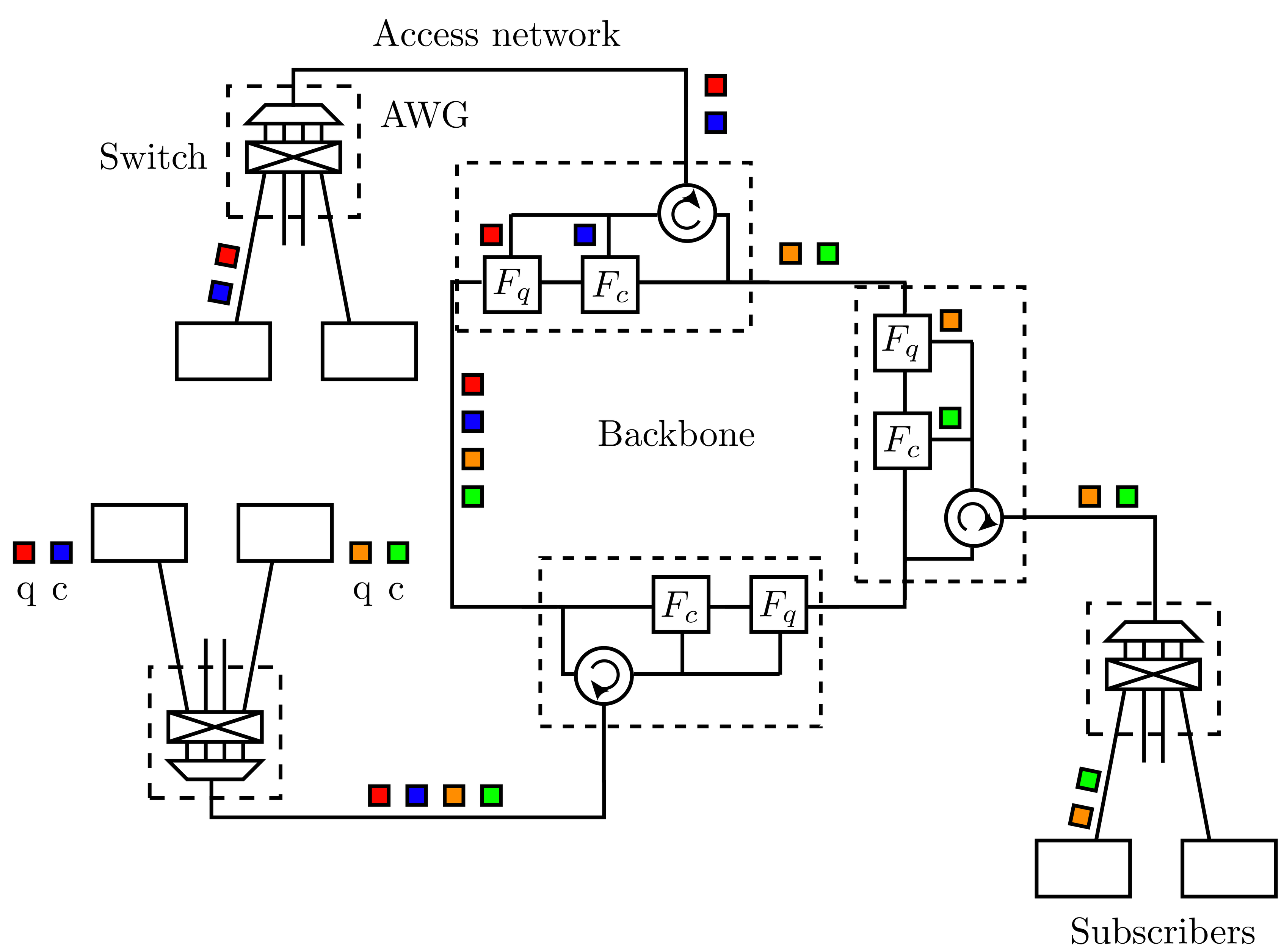

Fig. 3. Quantum-MAN. WDM-PON access networks are linked through a DWDM backbone network. Any pair of subscribers is capable of establishing a quantum channel and a classical channel no matter their access networks. The pairs of colored squares represent the channels of two simulated communications between multiple subscriber.

Acknowledgments

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